Experimental Investigation of Parity Conservation in the 14.4-kev Gamma Transition in Fe^{57}†

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An experiment using recoilless resonance scattering on the 14.4-kev $M1$ gamma rays of Fe^{57} was performed to set a limit on the degree of parity impurities in the nuclear states involved. The anisotropies of the $\Delta m=\pm 1$ gamma-ray transition rates were examined towards and away from the direction of nuclear polarization. The use of recoilless resonance scattering allows the problem to be so overdetermined that instrumental anisotropies could be cancelled by appropriate summing of data. No parity-nonconserving anisotropy was observed. Taking into account the slowness of the $M1$ transition compared to a parity-admixed $E1$ transition of single-particle speed, a factor of 100 in amplitude, the limit on $\mathfrak{F}$, the relative strength of a parity-admixed wave function is, $\mathfrak{F}\leqslant 10^{-5}$.

THIS letter reports on an experiment using recoilless resonance absorption to test the conservation of parity in the 14.4-kev gamma-ray transition in Fe^{57}. We shall detail only the unique features of this experiment since Mössbauer scattering of Fe^{57} gamma rays has been extensively reported in the literature.[1,2] The magnetic hyperfine structure of the $J=\frac{3}{2}^- \rightarrow J=\frac{1}{2}^-$ de-excitation consists of six lines corresponding to the $\pm\frac{3}{2}\rightarrow\pm\frac{1}{2}$, $\pm\frac{1}{2}\rightarrow\pm\frac{1}{2}$, and $\mp\frac{1}{2}\rightarrow\pm\frac{1}{2}$ m-state transitions (see accompanying figure).[3] These hyperfine lines have the theoretical intensity ratio of 3:2:1, and will be so labelled in the following discussion; + and − superscripts will indicate positive and negative Doppler velocities. In principle the method is analogous to that used by Wu *et al.*[4] who proved that parity was not conserved in the beta-decay interaction by detecting the spatial asymmetry of beta particles with respect to the direction of nuclear polarization. Similarly, parity nonconservation in the 14.4-kev $M1$ decay would exhibit itself as an asymmetric distribution of the $\Delta m=+1$ transitions with respect to the direction of nuclear polarization; the $\Delta m=-1$ transitions must then have the opposite asymmetry pattern. An additional and equivalent test of parity nonconservation is possible if equal populations of the polarized m states are originally available and if the hyperfine transitions can be effectively separated. In that case one need only detect a net difference in the counting rates of the $\Delta m=+1$ and $\Delta m=-1$ transitions as observed in one direction of nuclear polarization. (Such a net difference is, of course, equivalent to the observation of a net helicity of the $\Delta m=|1|$ photons.) These conditions are readily obtained via Mössbauer scattering. (At room temperature, the m state populations of the $J=\frac{3}{2}$ state differ by $\mu H/kT\approx 10^{-5}$.) The procedure was, therefore, to compare the 3^+ and 3^- transition rates parallel and antiparallel to the direction of nuclear polarization.

The experimental arrangement was as follows: A 1-millicurie Co^{57} source, plated and annealed onto an Armco iron foil which formed the return path of an electromagnet, was viewed tangentially (15°–20°) by a 1-mm thick NaI(Tl) detector. (Attempts to polarize the source perpendicular to the foil failed.) A 0.001-in. stainless steel (type 304) absorber, placed between the source and detector, was moved to and fro (∼1 cycle per sec) driven by a constant velocity, "heart-shaped" cam.[5] The degree of polarization of the m states was determined by the diminution of the No. 2 transitions which have a $\sin^2\theta$ distribution with respect to the nuclear polarization direction. In the accompanying figure the absorption spectrum at positive velocities for an unmagnetized source is shown. With the polarizing field used during the experiment, curve B, the nuclear polarization was 60%. Curve C shows the result of reorienting the Armco foil so that the grains were aligned with the magnetic field; the intensity of the No. 2 transitions is consistent with 100% polarization of the source.

The counting rates in the 14.4-kev photopeak, approximately 300 per sec, were recorded separately for forward and back motions; every twenty minutes the magnetization of the source was automatically reversed and the counts stored in separate scalers. As discussed above, reversal of the field direction should reverse an asymmetry in the 3^- to 3^+ intensity ratio due to parity nonconservation. By appropriate summing of the data it was thus possible to cancel systematic asymmetries due both to a net zero displacement of the velocity curve and to possible magnetic perturbations on the counter. The former effect arises from a small

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[1] R. V. Pound and G. A. Rebka, Phys. Rev. Letters **3**, 554 (1959).

[2] S. S. Hanna, J. Heberle, C. Littlejohn, G. T. Perlow, R. S. Preston, and D. H. Vincent, Phys. Rev. Letters **4**, 177 (1960).

[3] The m-state ordering in the figure is reversed from that of Hanna *et al.*[2] and Kistner and Sunyar[6] who used a positive μH interaction.

[4] C. S. Wu, E. Ambler, R. W. Hayward, D. D. Hoppes, and R. P. Hudson, Phys. Rev. **105**, 1413 (1957).

[5] Manufactured by the Allou Corporation, Waltham, Massachusetts.

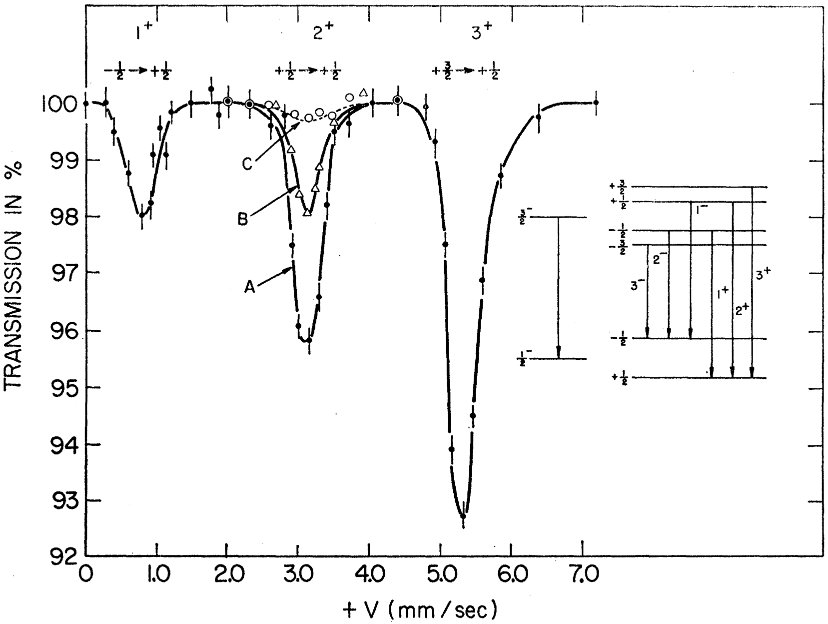

FIG. 1. Hyperfine structure of the 14.4-kev gamma-ray transition in Fe^{57}. The stainless steel absorber moves; the Co^{57} source plated onto Armco iron is stationary. Results for positive velocity (absorber moving towards the source) are shown. Curve A, the source is unmagnetized. Curves B and C show the diminution of the $+\frac{1}{2}\rightarrow+\frac{1}{2}$ transition resulting from the source being magnetized parallel to the detection direction. Curve C corresponds to orientation of the magnetic field parallel to the grain direction of the Armco foil.

chemical isomer shift[6] as well as a slight difference between plus and minus velocities of the absorber; the effect of this net zero displacement was first reduced to less than an 0.1% asymmetry by running at the crossing point (0.534 cm/sec) of the 3^+ and 3^- absorption curves. No asymmetries ($<10^{-4}$) due to magnetic field effects on the photomultiplier were observed as determined by counting without an absorber on the slopes of the 14.4-kev peak. Over a three-week period approximately 3×10^8 counts were registered, divided equally between the two field directions (denoted by $\uparrow$ and $\downarrow$) and plus and minus velocities. No asymmetry was found within statistical error, the gross result being

$$\Delta=\frac{[I_\uparrow^+ + I_\downarrow^-]-[I_\downarrow^+ + I_\uparrow^-]}{I_\uparrow^+ + I_\downarrow^- + I_\downarrow^+ + I_\uparrow^-}=(1.2\pm1.7)\times10^{-4}.$$

After correction for the $8\frac{1}{2}\%$ absorption (i.e., 91.5% background) of the No. 3 line and the 60% polarization of the source, the net asymmetry becomes

$$\Delta_{\text{net}}\leqslant 2\times10^{-3}.$$

This number implies parity conservation in both the electromagnetic transition and in the nuclear potential. Assuming that the former interaction conserves parity, it is possible to use the above number to set a limit on the degree of parity nonconservation of the nuclear states. The conditions of the experiment have been analyzed by Blin-Stoyle.[7] The asymmetry arising from admixtures of positive-parity states in the nuclear wave functions is given by

$$\Delta=2C\mathfrak{F}M_e/M_m,$$

where $\mathfrak{F}$ is the relative strength of the parity-admixed wave function, M_e and M_m are the matrix elements for the electric and magnetic transitions, and C is a ratio of Clebsch-Gordan coefficients; $C=1$ for this experiment. Thus a limit for $\mathfrak{F}$ involves an assumption of the strength of the parity-admixed ($E1$) transition. There are, unfortunately, no electric dipole strengths known in this region of the periodic table so that an ad hoc estimate must be made. [It would be unwise to estimate the $E1$ transition strength from known transitions in the heavier ($A\geqslant150$) or lighter ($A\leqslant20$) elements since the collective effects in the former region and the isotopic spin selection rules in the latter region do not apply to the 14.4-kev transition in Fe^{57}.] Assuming single-particle speed for the $E1$ transition, then $M_e/M_m\simeq10^2$ and, hence, $\mathfrak{F}\leqslant10^{-5}$. This limit is of the order obtained in other sensitive tests of parity conservation in strong interactions[8,9] and lends further weight to Blin-Stoyle's conclusion[7] that the present experimental limit on $\mathfrak{F}$ is $\mathfrak{F}\leqslant10^{-4}-10^{-5}$.

The technique used for this experiment is clearly restricted in application by the limited number of suitable sources, yet for those few the technique has the important advantage of measuring $\mathfrak{F}$ directly with minimum systematic errors.

ACKNOWLEDGMENT

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[9] F. Boehm and U. Hanson, Bull. Am. Phys. Soc. **4**, 460 (1959).